



Aalborg Universitet

**AALBORG UNIVERSITY**  
DENMARK

## Gain Optimization for STATCOM Voltage Control under Various Grid Conditions

Steinkohl, Joachim; Wang, Xiongfei

*Published in:*

Proceedings of the 2018 20th European Conference on Power Electronics and Applications, EPE'18 ECCE Europe

*Publication date:*  
2018

*Document Version*  
Accepted author manuscript, peer reviewed version

[Link to publication from Aalborg University](#)

*Citation for published version (APA):*

Steinkohl, J., & Wang, X. (2018). Gain Optimization for STATCOM Voltage Control under Various Grid Conditions. In *Proceedings of the 2018 20th European Conference on Power Electronics and Applications, EPE'18 ECCE Europe* (pp. 1-10). [8515604] IEEE Press. <https://ieeexplore.ieee.org/document/8515604>

### General rights

Copyright and moral rights for the publications made accessible in the public portal are retained by the authors and/or other copyright owners and it is a condition of accessing publications that users recognise and abide by the legal requirements associated with these rights.

- Users may download and print one copy of any publication from the public portal for the purpose of private study or research.
- You may not further distribute the material or use it for any profit-making activity or commercial gain
- You may freely distribute the URL identifying the publication in the public portal -

### Take down policy

If you believe that this document breaches copyright please contact us at [vbn@aub.aau.dk](mailto:vbn@aub.aau.dk) providing details, and we will remove access to the work immediately and investigate your claim.

# Gain Optimization for STATCOM Voltage Control under Various Grid Conditions

Joachim Steinkohl and Xiongfei Wang  
Aalborg University  
Pontoppidanstrde 111  
9220 Aalborg, Denmark  
Phone: +45 93562489  
Email: joa@et.aau.dk and xwa@et.aau.dk

## Keywords

«FACTS», «STATCOM», «Non-linear control», «Optimal control»

## Abstract

Static Compensators (STATCOMs) with voltage control are known for their fast reaction time to stabilize the grid voltage. For optimal dynamic performance it is essential to adjust the gain settings for the voltage controller, for different states of operation. This paper presents a new gain adaption algorithm to passively adapt to changes in the grid stiffness as well as to other dynamic voltage controlling devices, in order to provide stable STATCOM behavior in all system conditions. The proposed control will not need communication between the FACTS units. Which consequently simplifies and enhances the control systems even under severe grid changes.

## Introduction

A Static Compensator (STATCOM) is a device for advanced reactive power compensation [1]. It can be used to regulate the grid voltage, stabilize the power flow and improve the harmonic performance of power systems, such as wind parks.

It has been well understood that the voltage control of STATCOMs is highly dependent on the conditions in the grid, especially on the system strength, also called short circuit level (SCL) [2] and on other dynamic voltage controlling devices (e.g. other STATCOMs) installed nearby. If the devices can not adapt to these changing conditions, they can not guarantee optimal dynamic performances [3]. To allow the adaption to grid changes, a communication link between the voltage controlling devices is installed nowadays to adapt the gain of the voltage controllers [3]. Also the placement of the STATCOMs in the power grid has a huge effect on the interactions, as mentioned in [4].

Some researchers have focused on adaptive controller settings [5] or fuzzy control [6, 7, 8]. These control techniques are dynamically adapting the controller during the event to optimize the STATCOM's reactive output due to an external voltage change. Some take the effect of multiple nearby STATCOMs into account as well [9]. However, after the event all controller settings will be set back to the preset values. Also, these controllers are used to optimize the step response behavior of a STATCOM. Yet this is not the main purpose of the STATCOM. The main purpose is the reduction of voltage changes due to other grid events.

Other researchers use neuronal grid techniques [10] or other techniques, where the controller is trained in a huge number of simulations [11] to obtain the controller optimal behavior under various system

conditions. These methods may lead to unsatisfying operation, if there are grid situations that have not been foreseen by the engineers in the design phase.

This paper proposes a new algorithm for the optimal gain adaption of the voltage controller to system strength changes for single and multiple STATCOM systems. This method guarantees constant dynamic performances for a wide variety of system conditions. The proposed controller enables to place voltage controlling devices, as STATCOMs, without the need of communication or prior knowledge about grid parameters, such as distances to other voltage controlling devices. The proposed method allows therefore cost-effective and communication-failure-free dynamics over a wide range of possible future grid conditions. This superior feature is attractive to prevent critical infrastructure from failures and to improve the interoperability of dynamic voltage controlling devices from different vendors.

## STATCOM Voltage Control

The main task of STATCOMs is to stabilize the voltage in the power grid. STATCOMs are capable of providing both capacitive and inductive reactive currents and is therefore capable of lifting and lowering the grid voltage.

The strength of the power grid is a key value that has to be known to adjust the voltage controller to operate with its specified dynamics under all system conditions. Fig. 1 shows the control diagram of a STATCOM in voltage control mode with droop control.

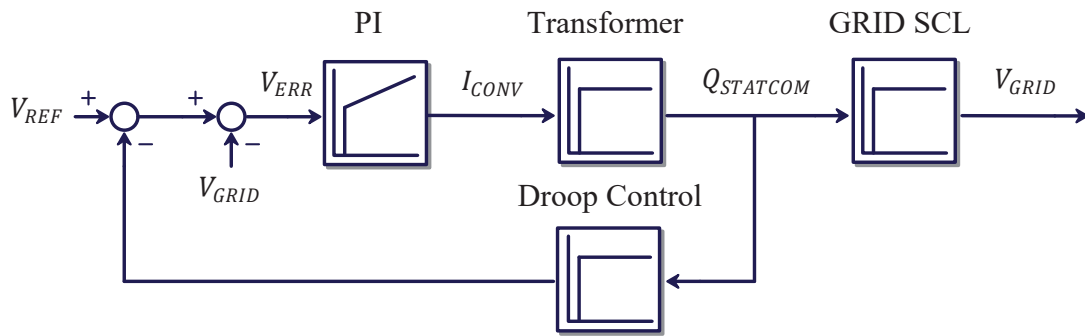


Fig. 1: STATCOM control scheme with droop control

The voltage reference setpoint is changed by the Droop factor (in %) multiplied with the reactive output of the STATCOM, which is normalized according to the rated reactive output of the STATCOM. Hence, a Droop of 1 % allows a voltage reference change in the steady state of 1 % when the STATCOM operates at nominal reactive output.

The equation of the Proportional-Integral (PI) controller is given by (1).

$$Gain \cdot \left( 1 + \frac{1}{T_N \cdot s} \right) \quad (1)$$

In this form the time constant  $T_N$  has to be set according to the filter time constant for the grid voltage measurement. Also a Proportional-Integral-Derivative (PID) control can be used with the proposed control. To achieve optimal response to voltage deviations [3], the gain value for the controller has to be set as below.

$$Gain = \frac{1}{\frac{1}{SCL} + \frac{Droop}{Q_{NOM}}} \quad (2)$$

With this gain adaption it is possible to have an optimal dynamic behavior between two steady state operation points. However, one main difficulty is the estimation of the SCL in the STATCOM controller and the interactions with different other voltage controlling devices.

The strength of the grid can be related to the impact of a reactive power change of a STATCOM on the resulting voltage deviation, which is given by

$$SCL = \frac{\Delta Q_{\text{STATCOM}}}{\Delta V_{\text{GRID}}} \quad (3)$$

If there are multiple dynamic voltage controlling devices (e.g., other STATCOMs) installed close to each other, the different voltage controllers have to be coordinated to prevent oscillations [3]. The coordination means a reduction of the calculated gain value from (2). This will then slow down the STATCOMs' dynamic responses to voltage deviations and lead to a stable behavior in the grid. To calculate the reduction, there has to be a communication link between the STATCOM controllers. This requires communication protocols between different vendors, as well as refurbishments when there are new STATCOM installed close to old installations.

The proposed controller allows the calculation of the optimal gain value without the need of communication with respect to other voltage controlling devices nearby.

## Proposed Control

The purpose of the proposed control is to optimize the dynamic response of the STATCOM to voltage disturbances. Fig. 2 illustrates the structure of the proposed gain adaption controller, which consists of three main blocks.

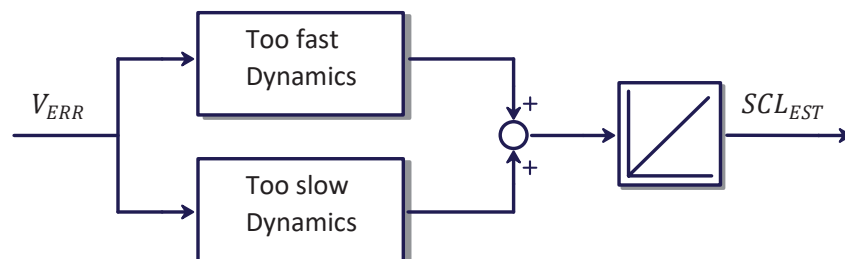


Fig. 2: Gain adaption controller overview

The block 'Too slow Dynamics' detects, if the strength of the power grid has increased since the last adaption. This implies that the STATCOM needs more reactive output to control the voltage in the grid accurately. The estimated SCL value for the gain calculation has to increase to compensate this.

The 'Too fast Dynamics' block is responsible for the detection of an SCL reduction in the grid since the last adaption. Then the estimated SCL value in the controller for the gain calculation has to be decreased. The used method to detect this behavior is described in the related Section.

The last block is an integrator. The output of the integrator is an estimation for the short circuit level of the grid. This value is then taken into (2) to calculate the gain for the PI controller also with respect to the droop control settings.

### Too slow Dynamics Block

The block 'Too slow Dynamics' is activated, when the stiffness of the grid has increased since the last adaption (e.g., due to the activation of loads and generation during daytime). The block detects, if the time to compensate a voltage disturbance is longer than the optimal compensation time. This time is highly dependent on the internal dynamics of the voltage controller. Especially the filters for the voltage measurement signal will affect the dynamics of the voltage controller. The time for the optimal voltage

disturbance compensation can be determined through simulations by tuning the voltage controller with step response tests and then applying voltage disturbances in the grid.

Fig. 3 shows the grid voltage (upper graph) and voltage error (lower graph) behavior during a grid voltage disturbances (load rejection). The figure shows the results with optimal gain settings and also the reaction of the STATCOM with increased grid strength and therefore too low gain settings.

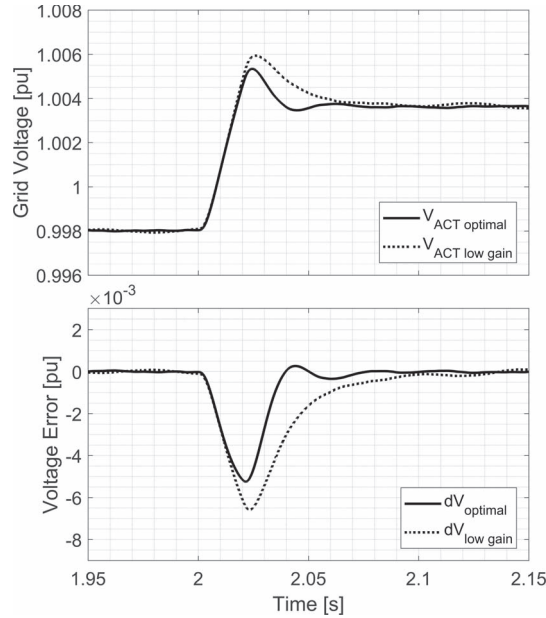


Fig. 3: Voltage error behavior after SCL increase

Fig. 4 shows the control diagram for the block 'Too slow Dynamics'. The only input for this block is the voltage error signal. It is used to detect, if the system strength has increased.

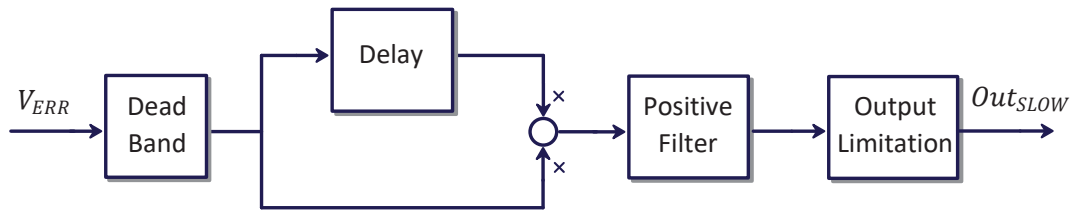


Fig. 4: Too slow dynamics block diagram

The control structure filters out small disturbances in the grid, e.g. due to measurement uncertainties, with the dead-band. Then the sign of the error value will be multiplied with itself delayed by the defined time constant. The resulting value will be filtered in a way that only positive values are allowed. This structure has been chosen, because it can also be used for the detection of fast controller dynamics.

The Output Limitation block in Fig. 4 is added to detect, if the STATCOM output is at its current limit. The current output has to be within the limits for a minimum 50 ms to be released. The STATCOM is not able to fully compensate the voltage error during severe events, like a grid fault. This would lead to a high output value of this controller structure, that is misinterpreted as an increase of the grid strength.

In the performed simulations, the voltage error can be compensated in 35 ms with the STATCOM reactive output change. This means, the error signal shall return to zero after a disturbance in 35 ms. If the error value is for a long time different from zero, then the output of detection block will be positive hence both the error signal and the delayed error signal will have the same sign.

The simulation results shown in Fig. 5 (a) represent the controller behavior under optimal gain settings. The upper graph shows the voltage error signal and the voltage error signal with time delay. The lower

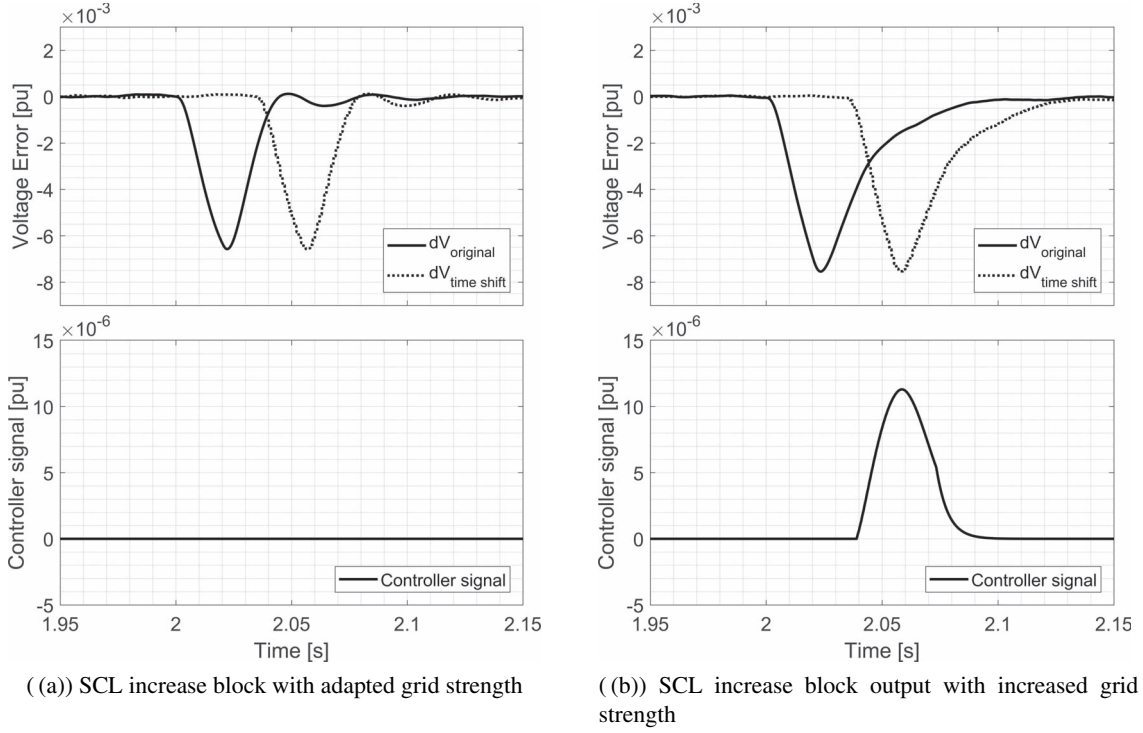


Fig. 5: Simulation results for the behavior under too slow dynamics

graph shows the output of 'Too slow Dynamics' block. In this simulation, there is no need to adapt the gain, because the system strength has not increased since the last adaption. If the STATCOM operates under optimal conditions, then the estimated SCL value will not be increased further.

In contrast, it can be seen in Fig. 5 (b), how the block behaves, if the grid strength has increased since the last adaption. Then, the output value of the block (Seen in the lower graph in Fig. 5 (b)) will be positive. This indicates that the estimated SCL has to increase to adapt to the increased grid strength.

The output of this logic is further processed in the integrator block. There it will increase the estimated SCL value for the gain calculation. Simulations with increased grid strength and the correct gain adaption is further shown in the Simulation Section.

### Too fast Dynamics Block

If the strength of the grid has decreased since the last adaption (e.g., during the night, when loads and generation units are reduced), then the STATCOM voltage control responds with too high reactive output change to a voltage disturbance. Therefore, it will cause overshoots in the grid voltage and damped oscillations with defined time constants will occur.

Fig. 6 shows the grid voltage (upper graph) and the voltage error signal (lower graph) with a STATCOM under optimal and too fast dynamics. The higher dynamics due to a high gain value will result in overshoots in the grid voltage and in oscillations around zero in the error signal. The block 'Too fast dynamics' has the purpose to detect these oscillations in the error signal. The block diagram is shown in Fig. 7. The limitation block is not needed for the detection of voltage overshoots.

The time delay for this detection block has been chosen to 20 ms, due to the simulation results shown in Fig. 6. Then, positive and negative values will overlap to result in a negative value after the multiplication. If the voltage measuring system time constant and the controller time constant are different from the simulations performed in this study, then the time delay has to be adapted to the changed STATCOM system time constants. The output of the block is filtered in a way that only negative values can pass. This block can therefore never increase the estimated SCL value.

The upper graph in Fig. 8 (a) shows the voltage error signal and the error signal with time delay of 20 ms. This simulation shows the controller behavior under optimal conditions, there is no need to adapt the

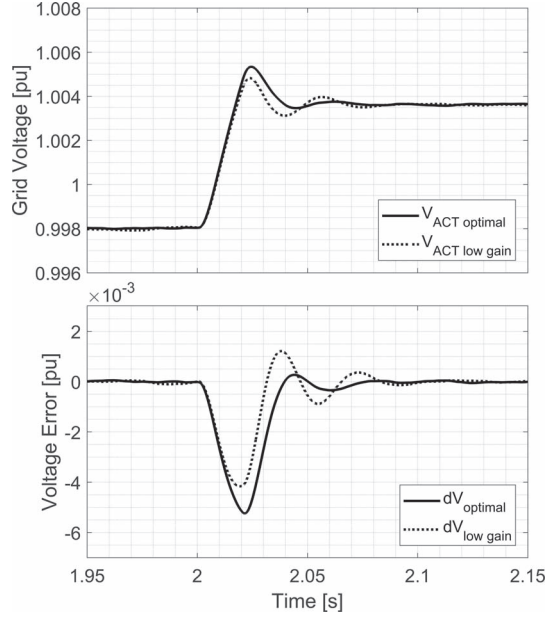


Fig. 6: Voltage error behavior after SCL decrease

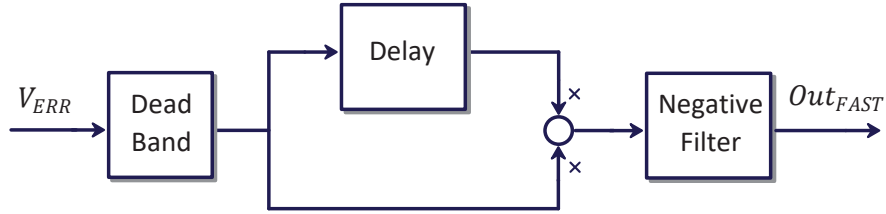


Fig. 7: Too fast dynamics block diagram

gain. The lower graph shows the output of the oscillation detection. It is zero all the time, because there is no adaption needed. These simulation results prove, that the estimated SCL value in the controller will not be reduced further, if it is not needed.

Fig. 8 (b) shows the block behavior if the strength of the grid has decreased severely. Then, there will be overshoots in the STATCOM reactive output, in the grid voltage and also in the resulting voltage error signal. The resulting negative output of the 'Too fast Dynamics' block (as shown in the lower graph in Fig. 8 (b)) will be a negative input to the integrator block. This will result in a reduction of the voltage controller gain and thus to a better dynamic performance.

These overshoots and error oscillations do not only occur if the grid strength decreases. They can also be seen if other dynamic voltage controlling devices, such as a second STATCOM, are activated close to the first STATCOM unit. These overshoots will then also lower the estimated SCL value for both voltage controllers. So the proposed algorithm can guarantee stable adaption to other voltage controlling devices as well as to grid strength changes. This will be further shown in the simulation results in the related Section.

### Integrator Block

The integrator block integrates the sum of the outputs of the two detection blocks. The detection blocks have the output zero almost all the time. This means, that the output of the integrator block will be a constant value for most of the time. The input of the integrator will only be not zero during grid voltage disturbances and then only, if the strength of the grid has changed. This will then change the estimated SCL value and the gain of the voltage controller accordingly.

This estimated SCL value will automatically be adapted to the influence of other dynamic voltage controlling devices as well. So the voltage controllers will adapt their dynamics themselves, if there are



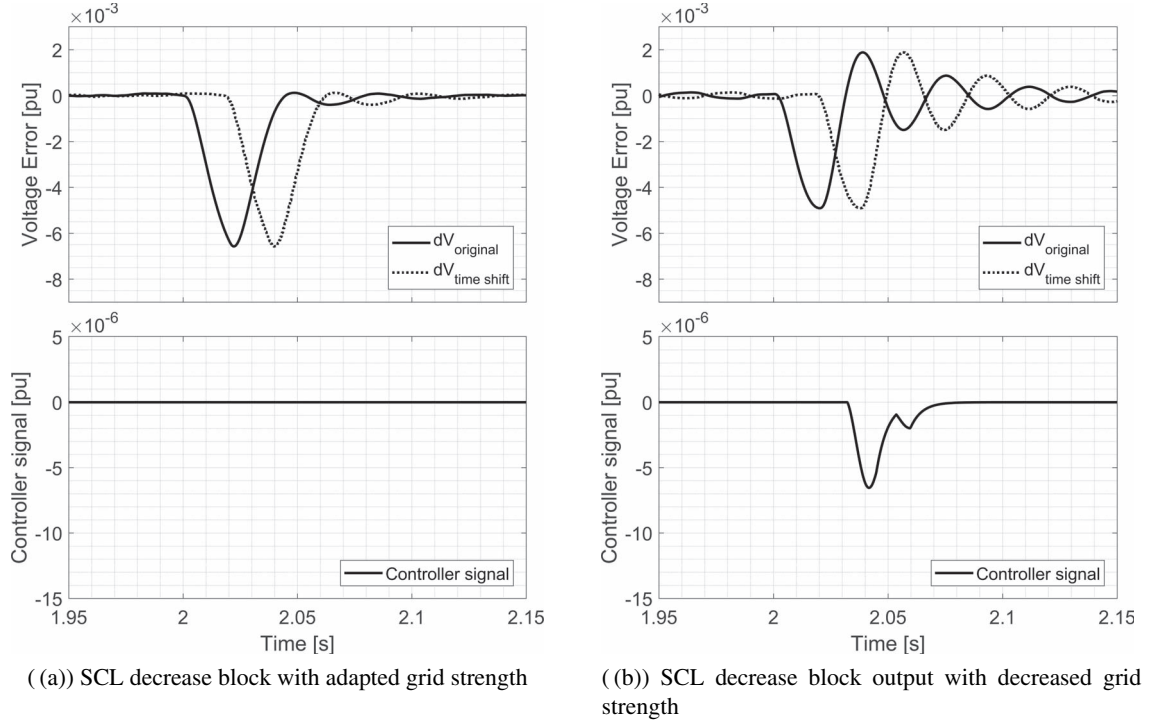


Fig. 8: Simulation results for the behavior under too fast dynamics

other voltage controlling devices energized or taken out of operation nearby.

## Simulation Verification

To verify this new proposed controller several simulations have been performed. The simulations are performed with EMTDS / PSCAD. A model for a delta configuration STATCOM has been used with controllable voltage sources as representations of the converter arms. The voltage will be simulated in 1 kV steps to represent the output of a converter with 1 kV submodules. The STATCOM is located behind a step-up transformer connected to a 220 kV AC voltage source with a series impedance to simulate different system strength conditions. For the simulations the grid strength will be set to different levels to show the adaption of the controller to these changes.

Step response tests are not a representation for the real system behavior. In a STATCOM application it is not allowed to periodically perform step response tests, because this would cause voltage fluctuations in the grid. So, for a real application test, the behavior due to a change in the grid voltage due to a disturbance is a better controller dynamics test. This voltage disturbance can be either due to a load switching or a line switching event. Several different voltage setpoint, droop control settings, grid SCL values and voltage disturbance levels have been set to verify the behavior under different conditions as well.

## Single STATCOM

The simulations for a single STATCOM installation have been performed with both an increase and a decrease of the grid strength at the beginning of the simulation. At first, the grid strength was increased from 1 GVA to 2 GVA at 3.5 sec. After this, small disturbances in the grid voltage are simulated and the proposed control is validated. The disturbances are the connection and disconnection of an inductive load.

Fig. 9 (a) shows the adaption of the controller behavior according to Section . The upper graph shows the grid voltage change due to the disturbance and then the control back to the reference value. The response of the STATCOM is too slow during the first distortion. After the first adaption of the estimated



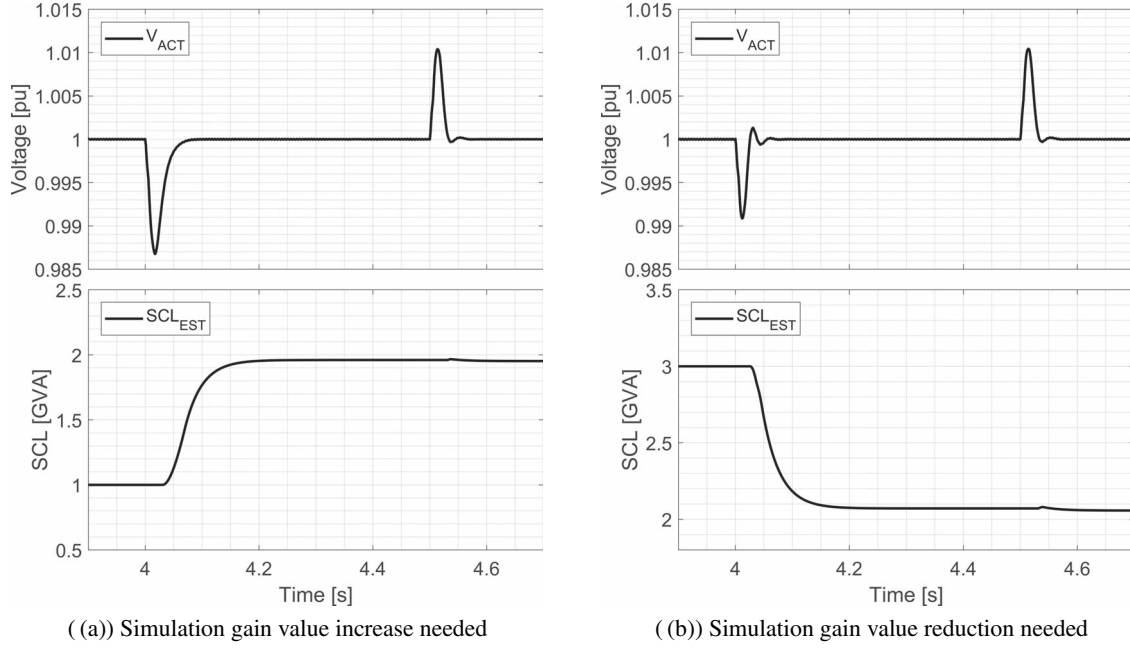


Fig. 9: Simulation results for the behavior under too fast dynamics

SCL value (shown in the lower graph) it can be seen, that the control is faster, but stable. The dynamic parameters are listed in Table I.

Table I  
Simulation Results with SCL Increase

	Disturbance Rejection Time	Overshoot
1 <sup>st</sup> Distortion	52 ms	0 %
2 <sup>nd</sup> Distortion	35 ms	4 %

After this, the simulations have been performed with decreased grid strength. In the beginning, the grid strength has been set to 3 GVA, then it has been reduced to 2 GVA at 3.5 sec. Afterwards small disturbances (load switching) in the grid voltage are simulated and the control adaption is validated.

The simulation results in Fig. 9 (b) shows that the estimated SCL value decreases if needed. The control dynamics are listed in Table II.

Table II  
Simulation Results with SCL Decrease

	Disturbance Rejection Time	Overshoot
1 <sup>st</sup> Distortion	30 ms	15 %
2 <sup>nd</sup> Distortion	34 ms	3 %

The simulation shows that the overshoots in the grid voltage due to a too high STATCOM output have been reduced from 15 % to 3 %.

## Two STATCOMs

If there is one STATCOM already in operation in the grid and then another STATCOM will be enabled nearby, then the gain has to adapt to this new grid condition. In this simulation one STATCOM (STATCOM 1) is in operation in the grid with a short circuit level of 2 GVA. Then, at the simulation time 4.1 sec,

the second STATCOM (STATCOM 2) will be energized and operational at the same bus. Therefore both STATCOMs will control the voltage in the grid. Both STATCOMs have the same voltage reference set-point (1 pu), the same rating (70 MVar) and also the same droop control settings (1 %). The result of this simulation is shown in Fig. 10 (a).

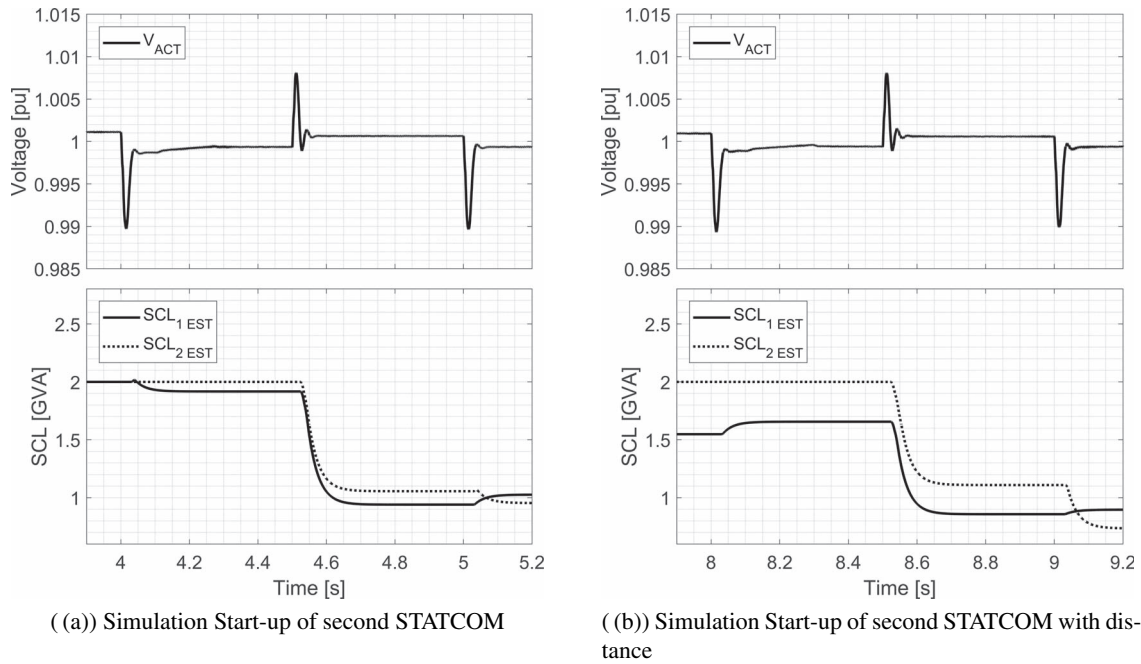


Fig. 10: Simulation results for the behavior under too fast dynamics

As shown in Fig. 10 (a) both STATCOMs adapt independently to the new grid condition and will lower their gain values in the controller to achieve satisfying dynamics after the adaption, as shown in Table III. This will allow both STATCOM units to operate with optimal dynamic performances and the grid voltage can be controlled as requested.

Table III  
Simulation Results with two STATCOMs

	Disturbance Rejection Time	Overshoot
1 <sup>st</sup> Distortion	35 ms	3 %
2 <sup>nd</sup> Distortion	25 ms	20 %
3 <sup>rd</sup> Distortion	36 ms	4 %

Also the performance of the adaption with distances between the different STATCOMs has been analyzed. For this, there is a 20 % additional grid impedance added before the connection points of the two separate STATCOMs. Fig. 10 (b) shows the results of this simulations. It can be seen, that the first STATCOM has settled to a different starting value, due to the additional impedance.

Table IV shows the performance of the STATCOMs at the connection point of STATCOM 1. When STATCOM 2 is also operational, both will adapt to the new grid constellation independently. It can be seen that the response fulfills the required dynamics and that the controller helps to stabilize also this kind of STATCOM placement in the power grid. This increase of performance is possible without communication being installed between the two units. Therefore, this new controller adaption, if installed in both STATCOMs, will allow the installation of multiple more dynamic voltage controlling devices nearby and with distances, if all have an adaption of the gain value as described in this paper.

Table IV  
Simulation Results with two STATCOMs and Distance

	Disturbance Rejection Time	Overshoot
1 <sup>st</sup> Distortion	34 ms	1 %
2 <sup>nd</sup> Distortion	28 ms	18 %
3 <sup>rd</sup> Distortion	35 ms	4 %

## Conclusions

The paper has discussed a new control method for a stable STATCOM voltage control. One advantage of this new controller is that it needs no communication between the STATCOMs or between the STATCOM and other dynamic voltage controlling devices. If all STATCOMs have this control, then future FACTS devices will no longer cause unwanted dynamic performances or the need of refurbishment with communication between the units.

The new control method is superior to other gain adaptations, because it provides an automated adaption of the gain value, not only cyclical, but whenever there is a severe event in the grid that forces the STATCOM to operate at a different point of operation. This controller adaption operates passively without any forced disturbance in the grid voltage caused by a triggered reactive output change. This new proposed controller has been verified by several simulations with many different setups.

## References

- [1] N. G. Hingorani, L. Gyugyi, and M. El-Hawary: Understanding FACTS: Concepts and Technology of Flexible AC Transmission Systems, Wiley Online Library, 2000, vol. 2
- [2] G. Romegialli and H. Beeler: Reactive Compensation. Problems and Concepts of Static Compensator Control, IEE Proceedings (Generation, Transmission and Distribution), 1981, vol. 128, no. 6., pp. 382- 388
- [3] Coordination of Controls of Multiple FACTS / HVDC Links in the Same System, ser. Brochures thématiques: International Conference on Large High Voltage Electric Systems, CIGRE, 1999, Chapter 4
- [4] B. Singh, N. Sharma, and A. Tiwari: Coordinated Control and Interactions between FACTS Controllers in Multi-Machine Power System Environments: An Overview & Issues, Fifteenth National Power Systems Conference (NPSC), IIT Bombay, 2008
- [5] Y. Xu and F. Li: Adaptive PI Control of STATCOM for Voltage Regulation, IEEE transactions on power delivery, 2014, vol. 29, no. 3, pp. 1002- 1011
- [6] S. A. Al-Mawsawi, M. Qader, and G. Ali: Dynamic Controllers Design for STATCOM, Iranian journal of electrical and computer engineering, 2004, vol. 3, no. 1, pp. 16- 22
- [7] J.-x. Xu, L.-c. Xiu, C.-c. Hang, C. Li, Q.-r. Jiang, and Z.-h. Wang: PI Control of STATCOM using Fuzzy Set and Auto-Tuning Techniques, IFAC Proceedings Volume, 1999, vol. 32, no.2, pp. 7340- 7345
- [8] A. K. Mahmood, I. I. Ali, and A. A. AL-Gailany: Voltage stability Improvements using Adaptive Controller for STATCOM, Journal of Engineering and Sustainable Development, 2018, vol. 21, no. 2, pp. 129- 148
- [9] L. Qing and W. Zengzeng: Coordinated Design of Multiple FACTS Controllers Based on Fuzzy Immune Co-Evolutionary Algorithm, Power & Energy Society General Meeting, IEEE, 2009, pp. 1- 6
- [10] S. Mohagheghi, Y. del Valle, G. K. Venayagamoorthy, and R. G. Harley: A Proportional-Integrator Type Adaptive Critic Design-Based Neurocontroller for a Static Compensator in a Multimachine Power System, IEEE Transactions on Industrial Electronics, 2007, vol. 54, no. 1, pp. 86- 96
- [11] V. Talavat, S. Galvani, and S. R. Marjani: Robust design of PSS and SVC using Teaching-Learning Based Optimization Algorithm, International Conference on Electrical and Electronics Engineering, IEEE, 2017, pp. 72- 75